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GUIDELINES
FOR
USE OF SILICA-FUME
IN
RIGID PAVEMENT

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1 INTRODUCTION

The silica-fume, a very fine non-crystalline silicon dioxide is a by-product obtained during manufacture of silicon and ferrosilicon alloys from pure quartz and carbon in electric arc furnace. It is also called microsilica or condensed silica-fume. It is a reactive pozzolana. The particles of silica-fume are extremely fine, most of them having diameter in the range of 0.03 and 0.30 micron. The specific surface of such fine particles can not be determined by Blaine's air permeability method. The nitrogen adsorption method (BET method) indicates a specific surface of more than 15 m^2/gm. Such a fine material has a very low bulk density of about 200-300 kg/m^3. As handling this light powder is difficult, it is densified by condensing with moisture, and then transported. In condensed form, the bulk density of silica-fume is about 500kg/m3. Silica-fume is usually used in concrete in proportion up to 10% by weight of cementitious material in the concrete mix, for development of high strength and abrasion resistance.

Because of high reactivity with calcium hydroxide in concrete, the resulting matrix is very dense and has low permeability. Additional benefits are reduced bleeding and improved cohesion of the concrete mix. Consequently, the porosity of concrete is also reduced.

The Rigid Pavement Committee (H-3) constituted a sub-group comprising Dr. S.C. Maiti, Shri Satander Kumar and Shri J. B. Sengupta for formulation of "Guidelines for Use of Silica Fume in Rigid Pavements". The draft guidelines Prepared by the sub-group was discussed by the Committee in series of meetings. The Rigid Pavement Committee (H-3) finalized the draft guidelines on 10th November, 2012 for placing before the HSS Committee. The Highways Specifications and Standards Committee (HSS) in its meeting held on 13th December, 2012. The Executive Committee in its meeting held on 19th December, 2012 approved this document. Finally, the Council approved this document in their meeting held on 8th January, 2013 at Coimbatore and authorized the Convenor, Rigid Pavement Committee (H-3) to incorporate the comments of Council members and place the same before the HSS Committee before publishing. Accordingly, H-3 Committee modified the draft which was approved by the HSS Committee in its meeting held on 19 July, 2013.

The composition of the Rigid Pavement Committee is given below:

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Vishnu Shankar Prasad	--------	Secretary General, IRC

2 SCOPE

Silica fume up to 10 as part replacement (by weight of cementitious materials) is suggested to be used in concrete as per IRC:15 for rigid pavement. Pavement Quality Concrete (PQC) with the use of silica fume shall have minimum flexural strength of 4.5 MPa and the corresponding compressive strength of 40 MPa. Such concrete is very cohesive, has low permeability, is highly abrasion resistant, and has longer service life. This concrete may be used in special cases in State and National Highways especially in coastal regions and where high abrasion resistance is required.

3 INFLUENCE OF SILICA-FUME ON THE PROPERTIES OF FRESH CONCRETE

The very large surface area of the particles of silica fume increases the water demand in concrete mixes. Therefore, it is necessary to use a superplasticizer in the mix. This would make it possible to use low water- cement ratio in concrete, for a given workability. The low water- cement ratio results in increased strength of concrete and reduced permeability.

Concrete mixes with a high content of cementitiuos materials tend to be sticky and to avoid 'sticky' mix, the water content of concrete mix should not be less than 150 kg/m^3 of concrete.

Generally, silica fume is compatible with all superplasticizers. The mixing of such fine powder in concrete should preferably be carried out in an efficient pan or paddle mixer or in a batching and mixing plant as per IS: 4925 and IS: 4926.

4 INFLUENCE OF SILICA-FUME ON PROPERTIES OF HARDENED CONCRETE

Concrete containing silica fume develops early as well as later compressive and flexural strengths of concrete. Typical relationship between water-cementitious materials ratio and 28-day compressive strength of concrete is shown in **Fig. 1**.

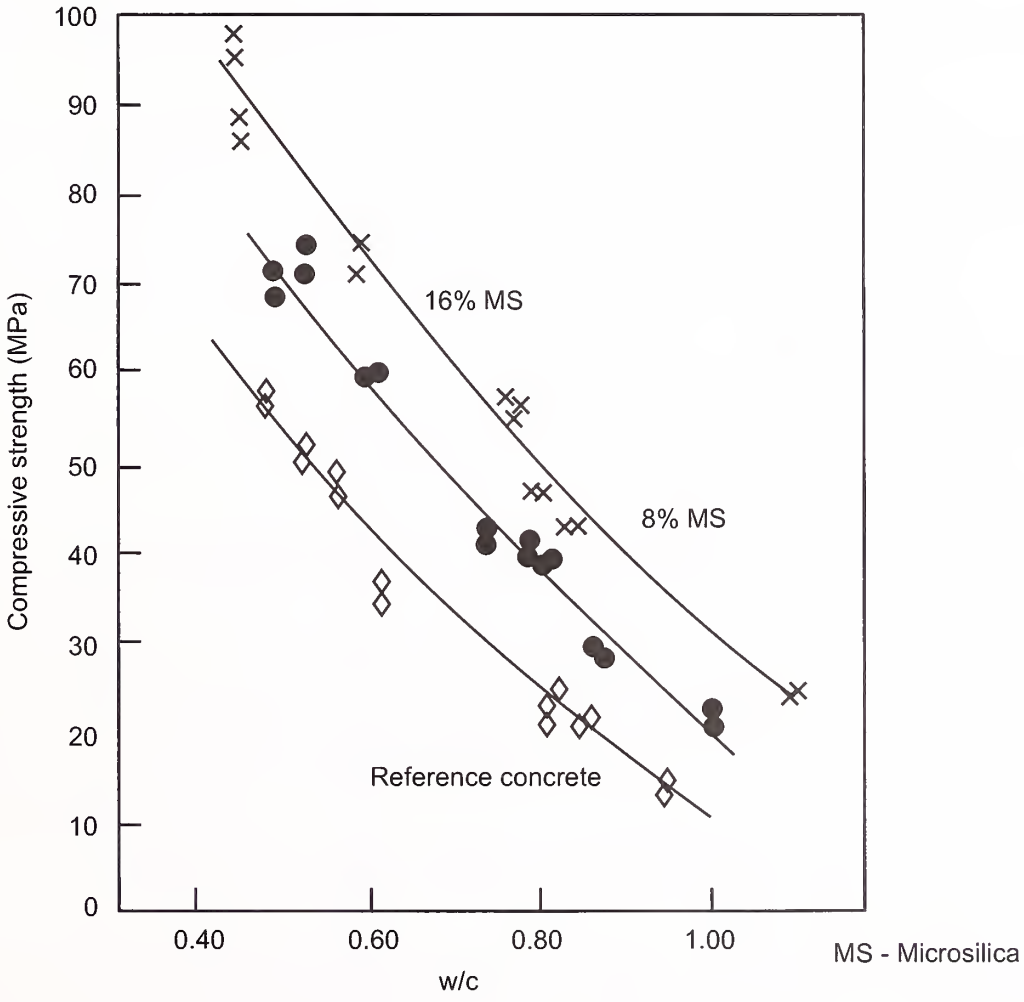

Fig. 1: Typical Results for Strength Improvement

The presence of silica-fume in concrete has a beneficial effect upon resistance to abrasion because, in the absence of bleeding, no weak top layer is formed, and also because of a better bond between the hydrated cement paste and the coarse aggregate, differential wear and loosening of particles do not occur.

5 ABRASION RESISTANCE OF SILICA-FUME CONCRETE

Low water-cement ratio high-strength silica-fume concrete shows greatly improved resistance to abrasion with low permeability. Abrasion resistance is an important area of application for silica-fume concrete such as at Toll Plaza and curves and where there is frequent change of grade (hill road). When the road is to be used by steel tyred or tracked vehicle, such as iron-tyred bullock carts, military tanks etc. as per IRC:15, use of silica-fume concrete for abrasion resistance has been recommended. This helps in reducing Foreign Object Damage (FOD) problem in airfield pavement also. The Norwegian practice of using studded tyres on cars during winter causes extreme wear of the road surface. Thus, in recent years, high-strength abrasion -resistant silica-fume concrete has become the paving material of choice, for high wear resistance. The Southern Illinois University test results indicate more than 100% improvement in abrasion resistance (abrasion index) with 10% silica-fume in concrete (**Fig. 2**) using ASTM C779 abrasion resistance test for horizontal surfaces (Ball revolution test method).

The abrasion index, as defined by the Australian Paving Association, given below may be adopted for determining the abrasion index:

$$IA = \frac{R^{½}}{P},$$

Where,

IA = Abrasion Index
R = Ball race revolution, in thousands,
P = Depth of wear, in mm.

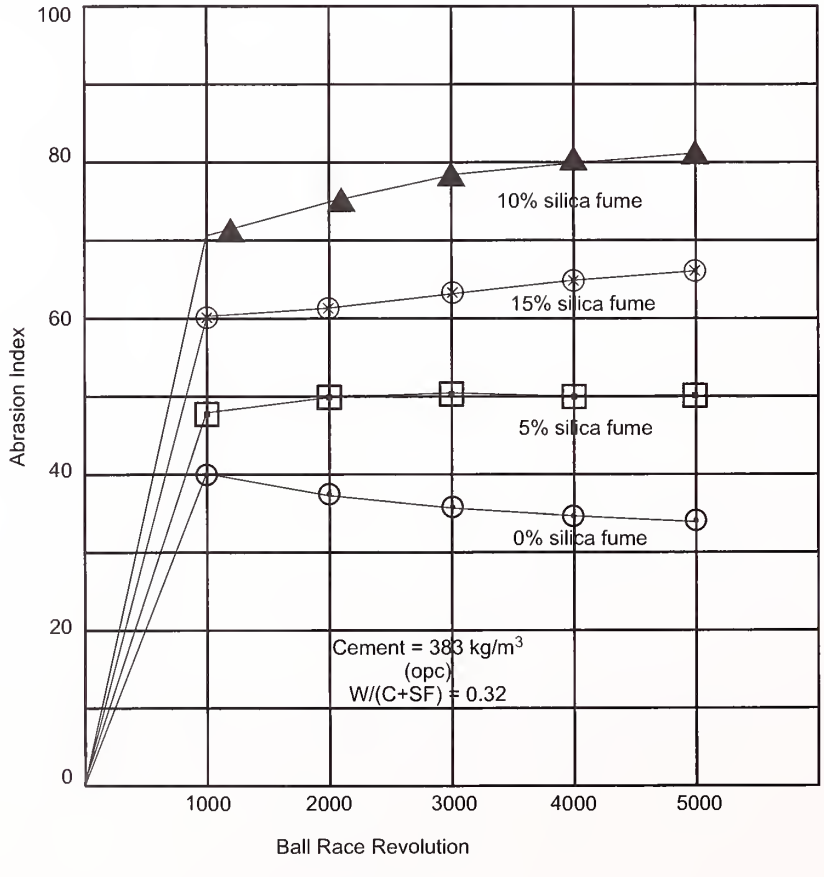

Fig. 2: Abrasion Index of Silica Fume Concrete (5 minutes testing period)

Their recommendation based on 5000 ball revolution for different traffic conditions are as follows:-

	Traffic condition		Abrasion Index
i)	For busy footpaths and malls with heavy pedestrian traffic	-	51
ii)	Public roadways	-	38
iii)	Car parking & vehicular traffic	-	31

These Guidelines recommend an abrasion index of 50 for rigid pavements.

6 STIPULATIONS IN INDIAN STANDARDS

IRC:15 stipulates use of silica-fume (as per IS: 15388, IS: 456 and IRC:SP:70 in concrete up to 10 percent by weight of cementitious materials. IRC:SP:70-2005 stipulate use of silica-fume in concrete to develop High Performance Concrete in bridges. The Indian Standard specification for silica-fume IS: 15388 covers the chemical and physical requirements of silica-fume for use in concrete.

The chemical and physical properties shall be as per **Table 1** and **Table 2** respectively.

Table 1 : Chemical Requirements of Silica-Fume

(As per IS: 15388)

Sl. No.	Characteristics	Requirement	Test Method
1)	Sio_2 percent by mass, min	85.0	IS: 1727
2)	Moisture Content, percent by mass, Max.	3.0	-
3)	Loss on ignition, percent by mass Max.	4.0	IS: 1727
4)	Alkalies as Na_2O, percent, max.	1.5	-

Table 2: Physical Requirements of Silica-Fume

(As per IS: 15388)

Sl.No.	Characteristics	Requirement	Test Method
i)	Specific surface, m^2/gm, Min.	15	BET Method, IS: 15388
ii)	Oversize, percent retained on 45 micron IS sieve, Max.	10	IS: 1727
iii)	Oversize, percent retained on 45 micron IS sieve, variation from average percent, Max.	5	IS: 1727
iv)	Compressive strength at 7 days as percent of control sample, Min.	85	IS: 1727

Notes:

1) Any one of the tests specified in (i) or (ii) and (iii) may be adopted.

2) For (iii), the average of 10 preceding tests or all of the preceding tests, if the number is less than 10.

3) For (iv), in accordance with the test method of IS: 1727, the value of factor N may be taken as 1, where $N = \frac{\text{specific gravity of silica-fume}}{\text{specific gravity of cement}}$

7 CURING

Immediately after the finishing operations have been completed, the entire surface of the newly laid concrete shall be covered against rapid drying, and cured as per IRC:15.

Curing shall be done by one of the following two methods:

i) By application of curing compound is followed by spreading of wet hessian cloth and moistening it regularly. In case of arid areas where water is extremely scarce, two applications of curing compound with moist curing by wet hessian cloth may be allowed at the discretion of the Engineer-in-Charge. Curing compound shall be resin based aluminized reflective type.

ii) For small works, curing can be done by manual methods using wet hessian cloth which is kept moist during curing period.

iii) Curing shall be done for a minimum period of 16 days.

iv) The water used for curing shall also be free from all injurious chemicals, like, chlorides and sulphates and shall meet the requirements of IS:456.

8 OPENING TO TRAFFIC

In general, traffic shall not use newly constructed pavement for a minimum period of 28 days as per IRC:15.

9 RECOMMENDATIONS FOR USE OF SILICA-FUME IN RIGID PAVEMENT

Because of good abrasion-resistant properties of silica-fume concrete, its use in rigid pavement is recommended. The concrete having 40 or 45 MPa compressive strength (4.5 or 5 MPa flexural strength), although has good resistance to abrasion, it is suggested that such concrete should include silica-fume upto 10 as part replacement of cementitious material, so that with better strength and abrasion-resistance characteristics of silica-fume concrete, the service life of the rigid pavements can be enhanced.

Because of part replacement of cement, and because of additional strength characteristics, the silica-fume concrete will not be very costly, as the reduction of cement will be higher than the percentage of silica-fume used, for the required flexural strength of concrete. The silica-fume concrete, however, will need more curing, than that required for normal concrete pavement, as is the case for concrete with all pozzolanic materials. In order to obtain improved abrasion resistance of concrete pavement with silica-fume, it is suggested to adopt a longer curing period.

The requirement of construction methodology, quality control, mix design and other requirement not covered above shall be followed as per IRC:15 and IRC:44.

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(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the code/guidelines/manual, etc. from the date specified therein)